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THE ANCIENT DIGITAL TERRAIN MODEL AND THE INFRASTRUCTURE OF THE ETRUSCAN CITY OF KAINUA

Replacing an early settlement of the second half of the 6th century BCE, Kainua was reconstructed at the beginning of the 5th century. This newly founded Etruscan city was built following a foundation rite and a rigorous urban plan, structured on four main orthogonal streets, the *plateiai*, perfectly oriented according to the cardinal points of the compass (E. Govi in this volume). Over the centuries this territory has undergone considerable geomorphological transformations and consequently the terrain elevation has changed significantly, so we tried to carry out a Digital Terrain Model (DTM), taking into account these transformations. DTM describes the three dimensional shape of the Earth's bare surface (excluding if possible any other features placed on it). Normally it is obtained by interpolation of known elevation points (e.g. stereo aerial photos) or contour lines (e.g. maps in analog or digital format) in order to produce a continuous surface. DTM is a particular type of spatial analysis of phenomena continuously changing in space (elevation values of terrain points above sea level). At the same time, through 3D display technologies, DTM is the basis of a more effective and realistic landscape representation model. Moreover, this particular kind of representation, considered from an analytical point of view as a visual analysis tool, may help to the development of new hypotheses or the confirmation of previous hypotheses in different research fields such, in this case, archaeology.

When positioning objects on the DTM, the analysis of metrology and structure of the infrastructure of the ancient city (streets and sewers) made it possible to create a renewed vision and to propose a hypothesis for reconstructing the incomplete, or as yet unstudied, parts of the city, which only further excavations will confirm.

1. The Digital Terrain Model

1.1 *Introduction*

DTM is a key element in order to have a correct virtual reconstruction of Kainua landscape from an urban to an architectural scale in a three-dimensional digital model, visualized in an interactive and immersive approach. For this purpose, in addition to DTM, were considered other important elements such as infrastructures like *plateiai* (main streets), *stenopoi* (minor streets), *Regiones* (sectors) and *insulae* (blocks), as well as sacred buildings and dwelling units detected in excavations and returned on the basis of philological studies of archaeological data.

Development of such a Digital Terrain Model was carried out by the use of GIS (Geographic Information Systems). GIS, as known, are defined by many authoritative authors such as tools for the representation of "geo-referenced entities" on the territory, able to manage and analyze geo-referenced data of different nature (physical, socio-economic, etc. and then related to "tangible and intangible phenomena") at different scale and time (Goodchild *et al.* 2001). In addition, the ability to manage different scales and particularly geographic features location characterizes GIS in a peculiar way comparing with other technologies (as for example BIM, which could be defined, simplifying the concept certainly much more complex, as a process using a kind of information system at the building scale). Hence, the need to work with spatially localized data at the urban scale in addition to the capability of GIS to integrate geographic information of different historical times and to analyze data to evaluate hypotheses or derive new information, has led to this choice.

The elevation profile of the Kainua area is evidently changed from the Etruscan period until today and the digital terrain model has been developed trying to take into account the geo-morphological transformations occurred in that area. Urban settlement area of Kainua, including neighboring areas, has mainly undergone natural and anthropic changes to date. One of the natural causes was erosion of the sedimentary rock on the S side along the river Reno, which, however, is very difficult to take into account. Among the anthropic known causes, the most important transformations were the construction of transport infrastructure and further settlements occurred from the 19th century that have significantly altered the landscape but also the geomorphology of certain portions of the area occupied by the Etruscan city. Probably the most significant one was the construction of the Porrettana main road from Pistoia in Tuscany to Emilia Romagna. Porrettana main road crosses Kainua area in EW direction and essentially divides the flatter urban area from the acropolis, which is located in the NW side at a greater height and with steeper slopes. In that area between the Porrettana main road and the acropolis, because of the excavations for road construction, were created differences in elevation of some meters, which certainly did not exist in the Etruscan period as well as the acropolis area slopes, then more accentuated in correspondence of *plateia* B, have become today less steep due to anthropic and natural phenomena.

1.2 *Altimetry survey*

To get an adequate representation of the Kainua Etruscan landscape for research purposes, taking into account area transformations, the DTM implementation was developed considering two important primary sources of data. To these two, a third supplementary topographic survey of the plateau area remained after the erosion of sedimentary rock, due to the river Reno that flows S, has been added. This third detailed elevation survey was carried out in the Kainua urban flat area, where today are concentrated the archeological excavations activities, with the use of Remotely Piloted Aircraft (RPA) technology.

The first primary source of data used for the DTM is a plano-altimetric survey, used as the base model of the entire archaeological area. Such elevation data, made available by CINECA (Calculation Interuniversity Consortium), obtained by the aero photogrammetry method and also used in previous projects, provide to date elevation profile and include a rather wide area near Monte Sole (located in a few km SE from the archaeological area of Kainua) containing the municipalities of Marzabotto, Monzuno and Grizzana Morandi (Guidazzoli 2007, 82). This survey was designed for a graphic representation of contour lines to the scale of 1:25,000 with an interval of 5 m.

The second main source of elevation data was obtained from two important publications of E. Lippolis (2001 and 2005) about topography of the acropolis archaeological area in the Etruscan period, included in *Regio* II and partially in the urban area (*Regio* IV, S of *plateia* B). From these studies, a map with a contour lines representation of the possible acropolis elevation profile at Etruscan time was carried out (Fig. 1). This elevation map takes into account the transformation in the elevation profile due to natural phenomena of erosive origin and due to the anthropic changes. In fact, in addition to the aforementioned construction of Porrettana main road in the first half of the 19th century, partly landowners for improvements works and partly archaeologists, who first began a systematic campaign of site studies, conducted other excavations in the same century.

The third complementary survey (Fig. 2) was a topographical survey by RPA technology (Dubbini, Curzio, Campedelli 2016). This is a high-level detail drone survey (including elevation points) of the urban area plateau (S of the acropolis) where today are concentrated archaeological excavations, obtained from a photogrammetric process based on a set of ground control points (Gaucci, Garagnani, Manferdini 2015). The latter survey is complementary to the other two and at the moment it has been used especially for georeferenced 3D modeling at building scale in the most significant places of the archaeological area. The survey was obtained, as known, from a photogrammetric process based on a set of control points (located on the archeological area polygonal region) taken to the ground with accurate GPS measurements (i.e. very close to the true value). From the photographic restitution of the three-dimensional model, the photogrammetric process returned, in addition to the topographic map, the Digital Terrain Model (as already mentioned limited to the area of the plateau S of the acropolis), in the

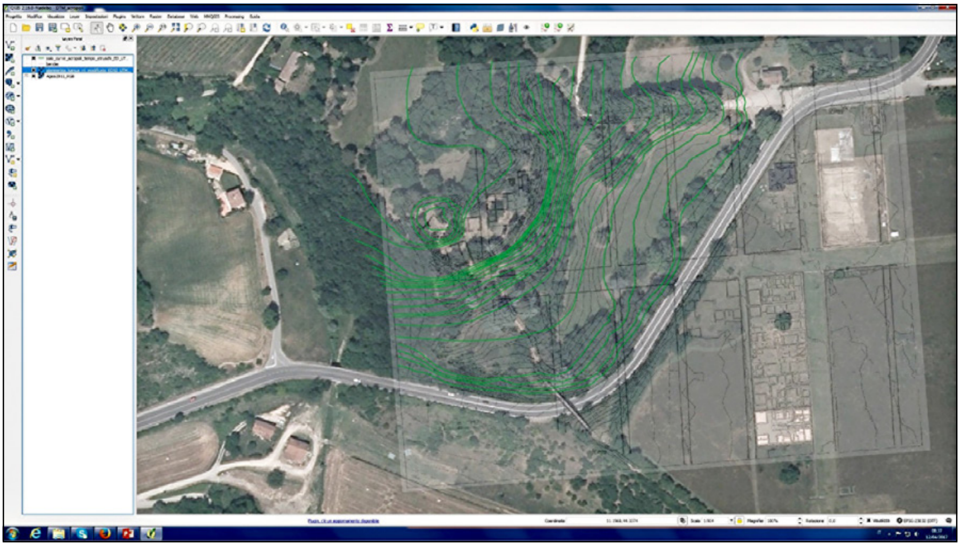

Fig. 1 – Topography map of acropolis area with contour lines in green derived from archeological studies.

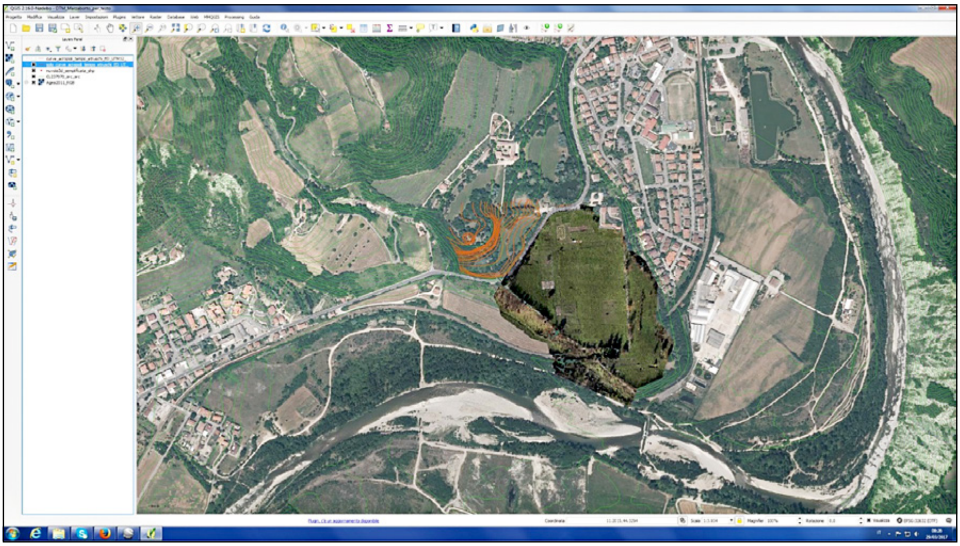

Fig. 2 – The three sources of elevation data: a) in green contour lines of the recent aerophotogrammetry, b) in orange acropolis contour lines and c) in dark green detailed photogrammetric survey by drone.

form of a cloud of elevation points with a very high resolution (centimeter size order). Photogrammetric restitution process gave more than 25 million points evenly distributed over an area of approximately 20 ha. Management of this huge amount of data by GIS is therefore, as one can easily imagine, quite complex and requires a "robust" geographic data management system (geodatabase) in the GIS environment. Therefore, we have chosen to operate using a DBMS able to supporting large geographical data tables. At present, the latter survey was not used to carry out the whole Kainua area Digital Terrain Model in order to speed up the entire modelling process and because, for present purposes, the elevation survey provided by CINECA has been considered sufficiently accurate. The elevation detailed survey was used instead for three-dimensional representation of some urban points of interest from which it is possible to visualize in an interactive and immersive approach individual or group of buildings modeled in three dimensions.

1.3 *Description of the interpolation procedure and software used to obtain final DTM*

For DTM processing and data management open source software was chosen. This choice was adopted mainly for reasons of convenience (reduction of costs) and was also suggested by the trend now in place in the Public Administration to privilege, wherever possible, the use of open source software tools. As known, there are advantages offered by free software (flexibility due to the availability of the source code, collaborative mode of development, etc.) as well as disadvantages like, for examples, spatial analysis tools not particularly complex or effective. However, in this case there were no special needs to justify the use of commercial software.

GIS software used to develop DTM from the two main elevation data sources in shape file format and WGS84 UTM32N coordinate system, was QGIS with the appropriate plugins. Furthermore, the need to manage and process APR survey, which generated a large point file, again oriented the choice to an open source relational geodatabase (Postgres with Postgis extension accessed by QGIS interface).

As mentioned before, plano-altimetric survey of the entire urban area including acropolis, provided by CINECA, reproduces the current state of elevation profile, which has undergone significant transformations especially from the 19^{th} onwards. Therefore, to reconstruct, as far as possible, the ancient terrain profile in the Etruscan period, we tried to integrate elevation data contour lines (with equidistance of 1 m) derived from Lippolis' studies to take into account previous elevation transformations.

To integrate the two sources of data and to make homogeneous equidistance of elevation data (contour lines) through an interpolation process we used a methodology in two steps:

– Replacement of contour lines, from the current survey (source provided by CINECA) and those obtained from Lippolis' studies, with elevation points. This step facilitates the reconstruction of altimetry profiles with a much more detailed control, recreating the continuity of terrain where discontinuities between the two sources occur, because of ancient heights integration derived from archeological excavations;
– Use of a TIN (Triangulated Irregular Network) point interpolation method to obtain a DTM in a raster (Grid) format with a cell size of 1 m.

1.4 *Results and final comment on results*

Outcome was considered acceptable for the research purposes, although there remains some uncertainty regarding acropolis elevation profile because of undergone significant transformations, which were mentioned previously. Before being used for the virtual reconstruction of Kainua landscape (including significant places of the archaeological area represented with more details) in a three-dimensional interactive and immersive digital model visualization, Digital Terrain Model was "tested" in GIS environment (Fig. 3). In this test,

Fig. 3 – Detail of the 3D representation test of DTM.

we used a QGIS plugin to visualize, in 3D mode, terrain profile with other superimposed layers of geographical features (raster, such as orthophoto of Marzabotto area, and contour lines vector layer) to highlight possible inconsistencies between DTM and features of the territory.

Even with the limitations already mentioned it was possible, however, to note that the first three-dimensional visualization with GIS tools and then with the modeling software used to reconstruct the landscape of the Etruscan settlement Kainua, appears consistent with the terrain model adopted. Finally, it should be noted that the limitations of the Digital Terrain Model regarding the accuracy did not significantly affect the objectives of the virtual reality reconstruction of the whole area of Kainua at urban scale that does not require special meter accuracy levels. On the other hand, in the plateau of the urban area, the much more detailed drone survey was used, as DTM basis, for the virtual reality 3D models at architectural and building scale in the interactive and immersive visualization, obtaining a much more precise outcome.

A.M.

2. The infrastructure of the ancient city

The reconstruction of the DTM of the Etruscan cityscape and the acropolis of the ancient Kainua, carried out by A. Muzzarelli, made it possible, for the first time, to connect the city grid to the morphology of the ancient terrain.

As highlighted by E. Govi (in this volume), the city grid of Kainua that we can currently observe on the site is the result of a foundation rite, which dates back to around 500 BCE and follows the exact orthogonal criteria of Greek origin according to the *Etrusca disciplina* (Sassatelli 1989-1990, 604-605; Malnati, Sassatelli 2008, 454-458). From a practical viewpoint, the first concrete result of the rite was the creation of the network of streets and sewers. As in the ancient foundation, the construction of the infrastructure has been the starting point in creating the virtual model on the DTM.

The first step has been the collection of all the various documentation regarding the structures. As underlined by E. Govi and A. Gaucci (in this volume), the information we have is the result of excavations that have been carried out during the last 150 years. GIS open source software (QGIS) was used to organize and analyse the data regarding both the construction and the metrology of the main and secondary streets, respectively called *plateiai* (Fig. 4, a) and *stenopoi* (Fig. 4, b), and of sewers. The software enabled the researcher to merge vast quantities of data into a single platform (Santocchini Gerg *et al.* in this volume). The initial two-dimensional representation, linked to the data collected from the literature, made it possible to formulate and elaborate proposals for the reconstruction of the areas that have not yet been investigated.

Fig. 4 – The *stenopos* on the western side of House 1, *Regio* IV, 2 (Romagnoli 2010, 238) and the *plateia* A.

2.1 *The archaeological analysis of the streets*

The first stage of the work was dedicated to the graphic representation of the streets. The digitalized cartography in GIS made it possible to conduct a metric analysis that allowed evaluations with noncritical errors for reconstructive purposes. Based on an Attic foot (29.6 cm) (Govi 2016, 228) and perfectly orthogonal and iso-oriented, the four *plateiai* divide the city into eight *Regiones* (Mansuelli 1965, 314-317). *Plateia* A is the main N to S artery that runs through the centre of the inhabited area, while the other three, *plateiai* B, C, D with orientation from E to W, are arranged at a distance of 144 m between B and C and 179 m between C and D respectively. These metrological differences between the areas of the city have been connected, by A. Gottarelli (2005, 123-127), to a specific astronomical circumstance during the foundation rite (Fig. 5). These main streets have different functions. *Plateia* B is a *via sacra* that connects the acropolis to the temples of the *Regio* I (Govi in this volume). *Plateia* A is of fundamental importance for viability, because of its N to S axis; it also represented the main street for those who came from the N, namely from the ancient Felsina (Bologna). Furthermore, it went on to connect with *plateia* D, the street that led to the eastern necropolis and to the Apennine mountain crossings.

These main streets that represent the skeleton of the whole city have been the subject of research since the first excavations by G. Gozzadini and E. Brizio in the second half of the 19th century, and after the Second World War by many scholars, among which we can mention P.E. Arias, G.A. Mansuelli, L. Malnati, G. Sassatelli (Romagnoli 2010, 246-250).

No substantial metrological difficulties were encountered during the creation of the graphic representations with 3D modelling software (Blender). The situation was different for the structural analysis of these streets. The information found in literature indicates how all the main streets (width 15 m)

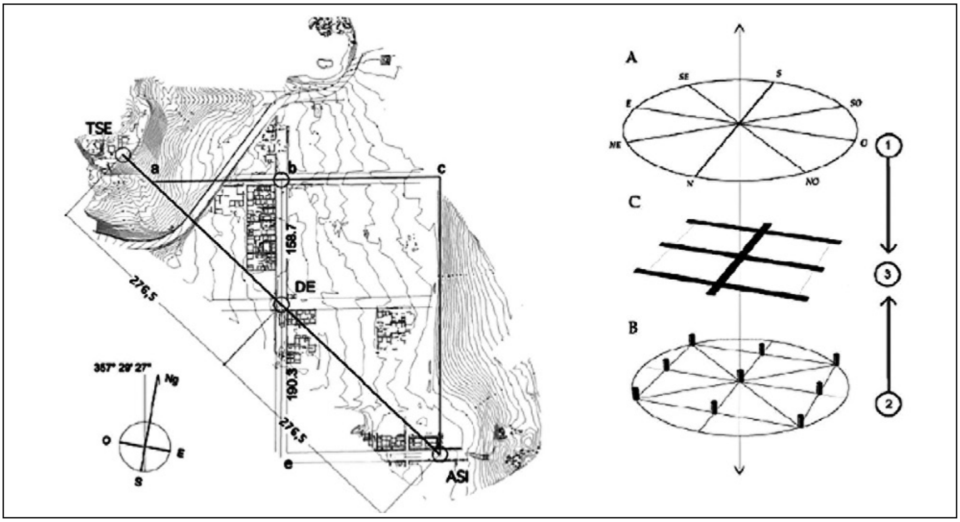

Fig. 5 – Schemes of the connection between the city plan and the position of the astronomical observations (Gottarelli 2005, 107; 2010, 32).

were made up of a central carriage lane built of small and medium pebbles with a sidewalk of smaller pebbles on either side (Romagnoli 2010, 223-254). The latest excavations carried out at the *Regio* V, *insula* 5 (Massa-Pairault 1997, 1-12) and in the House 1, *Regio* IV, 2 (Govi 2010, 21, 23-24), revealed well preserved portions of *plateiai* B, C, not only with the *glareatio* in the central carriage part, but also with portions of sidewalks covered in smaller pebbles. Regarding the *plateia* C, already excavated by Brizio (1891, 284-285) and partially by Mansuelli (1969, 229-232), during the excavation of the houses of the *Regio* V, 3 this *plateia* had been further detected (Massa-Pairault 1997, 7-12), but it still lacks of a detailed documentation. The same structure was firstly recorded in the *plateia* A during the excavation of the *Regio* IV, 1 conducted by Mansuelli (1963, 46; 1969, 229-232) and secondly in the *plateia* D, investigated for the first time by Gozzadini (1865, 52) and recognized as street by Brizio (1891, 285). All these findings have been fundamental for the creation of the volumes and reconstructive textures of the *plateiai*.

The *stenopoi*, usually with a width of 5 m, all oriented from N to S, divide the blocks (*insulae*) inside the *Regiones*. The *stenopoi* are made up of a simple lane arranged at regular intervals between 35.6 and 36.2 m (Govi 2016, 228-233) in the W of the *plateia A* while, to the E, the intervals vary. As a matter of fact, in the *Regiones* III and V the *insula* 4a is wider (45 m) and *insula* 4b is narrower (18 m). Moreover, the *stenopos* passing between the *insulae* 4a and 4b has an anomalous width of 6 m. This anomaly is now related with the construction of the temple of *Uni* and the organization of the sacred area of the *Regio* I by E. Govi (Garagnani, Gaucci, Govi 2016, 254-255; Govi 2017, 169).

The challenge to reconstruct the appearance of these minor streets was made greater by the incomplete documentation about the specific structure and the characteristic of the materials used for their construction. As a matter of fact, no *stenopos* has been extensively excavated except for the sections overlooking the areas of the block being studied. In particular, during the excavation of House 1 (*Regio* IV, 1), two traces of *stenopoi* have been revealed. Excavated for respectively 15 and 22 m, *stenopoi* B and C (Romagnoli 2010, 223-224) are, today, the best preserved sections with small and medium cobbles (Fig. 4, a). On the other side, the case of the *Regio* III suggests the same situation attested throughout the city and even supposing the presence of the *stenopoi*, but in this area the internal structure of the blocks is still unclear, except for the *insula* 5 (De Maria, Sassatelli, Vitali 1978, 58-63; Govi 2016, 230).

Therefore, although the general layout of the city is well-known, many questions and unresolved issues still surround the city infrastructure (e.g. the city way out). In some cases, these issues have been highlighted by the new DTM. An example is the connection between the *plateia* B and the sacred buildings of the acropolis. We focus on this issue, already discussed by E. Govi and A. Gaucci in this volume, from the point of view of the infrastructure. E. Lippolis suggested that the two westernmost *stenopoi* of the city would have continued along the hill (Lippolis 2005, 147), in spite of the 11 m difference in height. Although Lippolis has supposed the existence of the *stenopos* which run to the eastern limit of the acropolis by means of a trial excavation (Lippolis 2001, 263-264), there is instead no concrete evidence for the existence of it western counterpart, which passed between the podium D and the temple C in his opinion. Moreover, the height of the slope and the narrow distance between the *plateia* B and the terrace of the acropolis do not allow supposing a street that would have a too strong declivity.

2.1.1 The sewers

Further information that arose from the analysis of the streets via DTM regards the sewers. Although they are not completely excavated (Romagnoli 2010, 246-254, with previous bibliography), we can suppose they were present along all the *plateiai* and *stenopoi*, but not always on both sides. In fact, while they are always present on both sides of the *plateiai*, the situation concerning the *stenopoi* is quite different (Romagnoli 2010, 250-254).

From a metrological point of view, the sewers of the *plateiai* are uniform, measuring between 60 and 80 cm, as opposed to the *stenopoi* whose widths vary as it is for the *stenopoi* at the sides of House 1, *Regio* IV, 2 (Romagnoli 2010, 223-254).

The cohesive city planning, adopted during the foundation, is highlighted by their construction method. Indeed, during the excavations of House 1, *Regio* IV, 2, it was possible to establish that the street preparation, specifically the building of the border walls of the sewers, was carried out at the same time as the perimeter walls of the residence. This is clear from viewing *plateia* A and the houses of the *Regio* IV, 1 (Gaucci 2016, 165, 179, 191) and the houses in the southern part of the city (Govi 2010, 37, 46; Romagnoli 2010, 230-232).

The sewers separated the street system from the blocks and the private canals, i.e. sewers which came out from houses and were linked to the public network (Fig. 4, b), thought outlets (Mansuelli 1965, 314-325; Sassatelli 1991, 179-207). When the private and public canals were built, the constructors took advantage of the natural incline of the plateau so that the water flowed naturally from the city. The structure of the sewers also shows that they never cross the roads from N to S, while crossings E to W are evident. This way, a system of zones was created, where the sewers of the *Regiones* I-II, III-IV, V-VI are respectively connected (Fig. 6). A study carried out by G. Sassatelli (in Grillini, Sassatelli, Schiassi 1970, 237-239) has indeed suggested an area to the E of *plateia* C, unfortunately not yet established with certainty, where the sewers finally flow into.

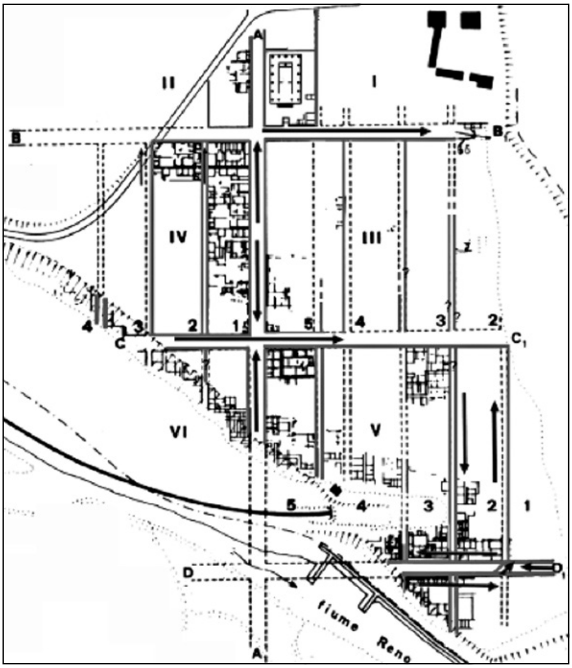

Fig. 6 – Sewers flow directions (Romagnoli 2010, 247).

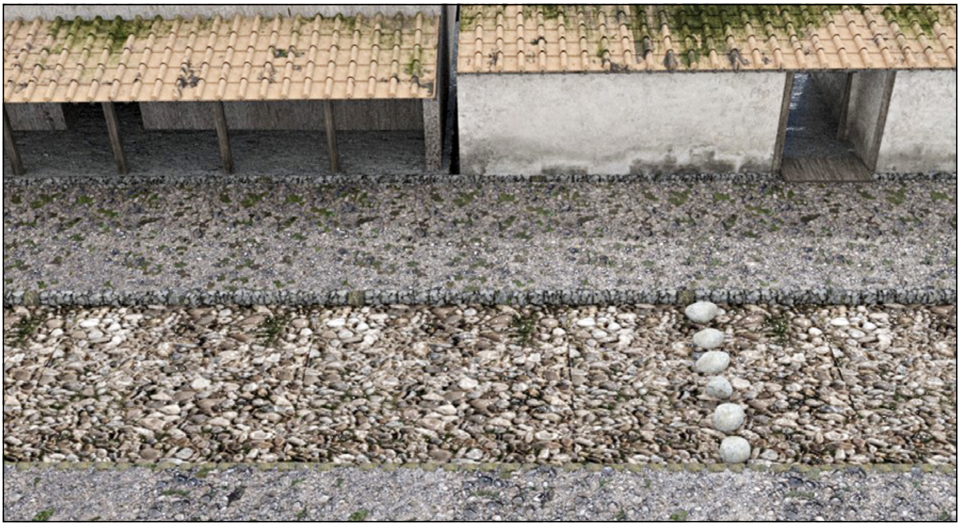

Fig. 7 – Elaboration of the virtual reconstruction of one of the main streets (*plateiai*), with the houses and the sidewalks divided by the sewers, and the line of pebbles as crosswalk.

Furthermore, it is not yet clear the system of the water outflow, which from the houses roof had to be conveyed in the sewers and especially beyond their coverage. In fact, this last aspect concerning the sewers coverage (except the ones close to the houses entrance) has been interpreted in different ways: they could be covered or usually opened (Romagnoli 2010, 229), as argued in this project. Moreover, it is still under debate how the water coming from the roofs could be conveyed into the public sewers (Gruška, Mancuso, Zampieri in this volume).

To conclude, the reconstruction of the streets and sewers together with the elaboration of the buildings (Fig. 7) have allowed to highlight features and problems concerning not only their planning and building, but also their functional aspect. Nevertheless a lot of questions remain open.

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ABSTRACT

This paper aims to explain the creation of the Digital Terrain Model (DTM) of Kainua, an Etruscan city founded, following a rigorous urban plan, at the beginning of the 5th century BCE. This DTM was used as the basis for the virtual reconstruction of Kainua landscape from an urban to an architectural scale in a three-dimensional digital model, visualized in an interactive and immersive approach. The DTM was developed using different sources of elevation data, in order to take into account the geo-morphological transformations occurred in that area from the Etruscan period to the present day. The causes of these changes were natural (due to erosion phenomena) and anthropic (due to excavations for construction of transport infrastructure as well as those which occurred partly due to improvements made by landowners and partly to archaeologists who first began a systematic campaign of site studies). On positioning on the DTM, an analysis of the metrology and of the infrastructure of the ancient city (streets and sewers) made it possible to create a renewed vision and to propose a hypothesis for reconstructing the incomplete, or as yet unstudied, parts of the city, which only further excavations will confirm.